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(81)	Designerade stater Designated states	AP: all, EA: all, EP: all, OA: all, AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LI, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW
(21)	Patentansökningsnummer Patent application number	PCT SE03/00671
(86)	Ingivningsdatum Date of filing	2003-04-25

Stockholm, 2004-05-07

För Patent- och registreringsverket
For the Patent- and Registration Office

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AN IMPROVED DIRECTIONAL COUPLER

TECHNICAL FIELD

The present invention relates to a directional coupler comprising coupled lines.

BACKGROUND

A directional coupler is a well known four port element for radio frequency equipment. This device allows a sample of a radio or microwave frequency signal, which is provided to an input port and received at an output port, to be extracted from the input signal. Properly designed, the directional coupler can distinguish between a signal provided to the input port and a signal provided to the output port. This characteristic is of particular use in a radio frequency transmitter in which both the transmitted signal and a signal reflected from a mismatched antenna can be independently monitored. To obtain such performance, directivity of the coupler should be very high. Directivity of the coupler is high if so called "compensation conditions" are fulfilled. There are two compensation conditions, assuming validity of quasi-static approximation: 1) the capacitive and inductive coupling coefficients are equal, and 2) the coupler is terminated with the proper impedances (preferably 50 Ohms) – for more details see for instance: K. Sachse, A. Sawicki, Quasi-ideal multilayer two- and three-strip directional couplers for monolithic and hybrid MICs, IEEE Trans. MTT, vol. 47, No. 9, Sept. 1999, pp. 1873 – 1882.

Directional couplers intended to be used as monitors of transmitted power or power reflected from an antenna should have weak couplings (coupling of -30 to -40 dB) and high directivity (at least 20 dB). It is a very known property of directional couplers that directivity is lower for weakly coupled lines than for tightly coupled ones. Therefore, couplers having a weak coupling are difficult to make so that they are compensated. The article mentioned above by K. Sachse and A. Sawicki describes

couplers that are suitable for tight couplings, in the region of –3 dB to –8 dB, corresponding to coupling levels of 0.7 to 0.4. However, weak couplings under compensated conditions can not be obtained with the configurations in the article.

A good solution for these types of couplers is utilizing pure strip line configuration with homogeneous dielectric media. Unfortunately, this solution can be applied only for the couplers built as separate components. They can not, or can hardly be applied in an integrated circuit environment where transmission lines carrying a power signal are integrated mainly on the top surface of a multilayer printed board.

Directional couplers formed in coplanar or conductor-backed coplanar and quasi-strip line configurations are described in the US 4,288,760 patent, and here presented in fig. 1 and fig. 2, respectively. It can be seen that in both configurations the coupled lines are located at a vertical distance from each other, and also at a horizontal distance from each other. Compensation of these couplers is achievable at only one mutual position of coupled strips, and the corresponding coupling is at a dozen or so dB level. In these couplers, if compensation conditions are to be kept, only a small reduction of coupling is possible by increasing the height of the dielectric layer separating the coupled strips. Moreover, the configuration shown in fig. 1 is not convenient for multilayer boards, because positions of the external ground planes, e.g. formed by a mechanical construction, are very critical for parameters of the coupler, and small alterations of external ground plane positions will cause large deviations of the coupler parameters.

SUMMARY

An object of the invention is to present a directional coupler that can assure a wide range of weak couplings realized under compensation conditions.

Another object of the invention is to present a directional coupler configured in multilayer printed circuit environment that can assure a wide range of weak couplings realized under compensation conditions.

These objects are reached by a directional coupler comprising coupled lines including a first and a second line characterized in that it comprises a tuning ground plane, that, in a direction perpendicular to the tuning ground plane, the first and the second line are located at a first vertical distance from each other, that, in a direction perpendicular to the tuning ground plane, the first line and the tuning ground plane are located at a second vertical distance from each other, that, in a direction parallel to the tuning ground plane and perpendicular to a longitudinal direction of the coupled lines, the first and the second line are located at a first horizontal distance from each other, that, in a direction parallel to the tuning ground plane and perpendicular to the longitudinal direction of the coupled lines, the first line and the tuning ground plane are located at a second horizontal distance from each other, and that it comprises a ground plane which, in a direction perpendicular to the tuning ground plane, is located at a third vertical distance from the first line, whereby the third vertical distance is larger that any of the first or second vertical distances.

The tuning ground plane, located at a vertical distance and a horizontal distance from the first line, contributes substantially to possibilities of adjusting the coupling level and compensating the coupler. This allows achieving a wide range of weak coupling coefficients, in which the coupler is compensated. In turn, this makes possible to obtain high directivity of the coupler.

Preferably, the directional coupler comprises at least four conductive layers, whereby at least three dielectric layers are interposed between the conductive layers. Thereby, the coupler configuration is convenient to be manufactured in a standard multilayer printed circuit board technology.

Preferably, an electrical length of the directional coupler is a quarter or less of the wavelength.

BRIEF DESCRIPTION OF DRAWINGS

Below, the invention will be described in detail with reference to the drawings, in which

- fig. 1 and 2 show sectional views of coupled lines directional couplers according to known art, sectioned perpendicular to the coupled lines,
- fig. 3 shows a sectional view of a coupled lines directional coupler according to a first embodiment of the invention, sectioned perpendicular to the coupled lines,
- fig. 4 shows a diagram with coupling coefficients for the directional coupler shown in fig. 3, and a cross-section corresponding to the one in fig. 3 to explain variables in the diagram,
- fig. 5 shows a sectional view of a coupled lines directional coupler according to a second embodiment of the invention, sectioned perpendicular to the coupled lines,
- fig. 6 shows a diagram with coupling coefficients for the directional coupler shown in fig. 5, and a cross-section corresponding to the one in fig. 5 to explain variables in the diagram,
- fig. 7 shows a sectional view of a coupled lines directional coupler according to a further embodiment of the invention, sectioned perpendicular to the coupled lines,
- fig. 8 shows a diagram with effective dielectric constants calculated for two orthogonal modes propagated in the coupled lines in the configuration shown in fig. 7, and a cross-section corresponding to the one in fig. 7 to explain variables in the diagram, and
- fig. 9 and 10 show sectional views of a coupled lines directional couplers according to additional embodiments of the invention, sectioned perpendicular to the coupled lines.

DETAILED DESCRIPTION

In Fig. 3, cross-section of a structure of a coupled lines directional coupler according to a first embodiment of the invention is presented. Like other embodiments presented here it is suitable for multilayer printed circuit technologies and weak couplings. It comprises a first 1, a second 2 and a third 3 dielectric layer in the form of substrates. The first dielectric layer 1 is located above the second dielectric layer 2, and the second dielectric layer 2 is located above the third dielectric layer 3. The coupler comprises a first 4, a second 5, a third 6 and a fourth 7 conductive layer. The first conductive layer 4 is located on top of the first dielectric layer 1. The second conductive layer 5 is located between the first dielectric layer 1 and the second dielectric layer 2. The third conductive layer 6 is located between the second dielectric layer 2 and the third dielectric layer 3. The fourth conductive layer 7 is located below the third dielectric layer 3.

Coupled lines 8, 9, in the form of strips, preferably straight and parallel, and having a longitudinal axis, here referred to as a first 8 and a second 9 line, are formed in the first 4 and the third 6 conductive layer, respectively. The first and second lines could also be arranged so that the distance between them varies, for example in a case where one of them, or both, are curved, or in a case where they are straight but non-parallel: For this presentation, the longitudinal axis of the coupled lines is defined as the longitudinal direction of the mass distribution of both lines. In a case where the coupled lines are straight and parallel, the longitudinal axis of the coupled lines is parallel to each of them. Since the first and the second line 8, 9 are formed in separate conductive layers, they are located at a first vertical distance from each other. In this embodiment, the first vertical distance is approximately equal to the sum of the thicknesses of the first 1 and the second 2 dielectric layer. Also, the first and the second line 8, 9 are located at a first horizontal distance 14 from each other.

In the first 4, second 5, third 6 and fourth 7 conductive layer, a respective first 10, 10', second 11, 11', third 12, 12' and fourth 13 ground plane is formed. The fourth ground plane 13 is also referred to as a lower ground plane 13. The first 10, 10', second 11, 11', and third 12, 12' ground plane each include a first region 10, 11, 12, and a second region, 10', 11', 12', which are, in a direction parallel to the ground planes and perpendicular to the longitudinal direction of the coupled lines 8, 9, located on opposite sides of the first line 8.

The first region of the second ground plane 11, which is, in a direction parallel to the ground planes and perpendicular to the longitudinal direction of the coupled lines 8, 9, located on the same side of the first line 8 as the second line 9, is here referred to as a tuning ground plane 11. As can be seen in fig. 3, the tuning ground plane 11 is, in a direction perpendicular to the ground planes, located between the first 8 and the second line 9. The first line 8 and the tuning ground plane 11, formed in separate conductive layers, are located at a second vertical distance from each other. In this embodiment, the second vertical distance is approximately equal to the thickness of the first dielectric layer 1. Thus, in this embodiment the first vertical distance is larger than the second vertical distance. The lower ground plane 13 is, in a direction perpendicular to the tuning ground plane 11, located at a third vertical distance from the first line 8, whereby the third vertical distance is larger that any of the first or second vertical distances. The third vertical distance is approximately equal to the sum of the thicknesses of the first 1, the second 2 and the third 3 dielectric layer.

Further, the first line 8 and tuning ground plane 11 are located at a second horizontal distance 15 from each other.

The first 10 and the second 10' region of the first ground plane are placed with preferably the same distances 16, 17 from the first line 8. However, as an alternative, the distances 16, 17 between the first region 10 of the first ground plane and the first

line 8, and the second region 10' of the first ground plane and the first line 8 could be un-equal. The second region of the second ground plane 11' and the second region of the third ground plane 12', both located on the same side of the first line 8, are preferably located at the same horizontal distance 16 from the first line 8 as the second region of the first ground plane 10'. This will be practical, since it will facilitate the introduction of via holes 19 described below. However, as an alternative the second region of the second ground plane 11' and the second region of the third ground plane 12' could be located at horizontal distances from the first line 8 that are un-equal to the distance 16 between the second region of the first ground plane 10' and the first line 8. The first region of the second ground plane 12, which is located on the same side of the first line 8 as the tuning ground plane 11, is located at a distance 18 from the second line 9. The first region of the first 10, second 11, and third 12 ground plane and the lower ground plane 13 are connected by means of a plurality of via holes 19 placed along the coupled lines 8 and 9, and the second region of the first 10', second 11', and third 12' ground plane and the lower ground plane 13 are also connected by means of a plurality of via holes 19 placed along the coupled lines 8 and 9.

Fig. 4 shows results of calculations of the coupling coefficients of the coupler described above, as a function of the horizontal distance 15 between the first line 8 and the tuning ground plane 11 (fig. 3), and the horizontal distance 14 between the first 8 and the second 9 line as a parameter. The permittivity of the dielectric layers is referred to as eps1, eps2, and eps3. eps1 and eps3 values are typical for a core material, and eps2 value is typical for a prepreg material. kc and kl refer to the capacitive and inductive coupling coefficients, respectively. The directional coupler is compensated if these two coefficients are equal and the ports of the coupler are terminated, in this case with 50 Ohms impedance. It can be seen in fig. 4 that the configuration assures wide range of weak couplings, i.e. from -20 dB to -37 dB and beyond, while being compensated. To clarify that these are weak coupling levels, it is pointed out that –20 dB correspond to a ratio between the power transferred to the

second line 9 and the total power propagated in the main line 8 of 0.01, and –30 dB correspond to a ratio between the power transferred to the second line 9 and the total power propagated in the main line 8 of 0.001. The ground plane 11 has a central function in adjusting the coupling level and to compensate the coupler. The coupling level can be adjusted by changing the distance 14 between the first line 8 and the second line 9 and adjusting the distance 15 between the first line 8 and the tuning ground plane 11. The adjustment of the distance 15 between the first line 8 and the tuning ground plane 11 will also tune the coupler to the compensation conditions. At the same time width of the first line 8 and the second line 9 should be adjusted to fulfill the matching condition of the compensation conditions. These widths vary from 120 to 126 mils for the line 8 and from 21 to 31 mils for the line 9 when the first 14 and the second 15 horizontal distances vary over the range shown in fig. 4.

Fig. 5 shows a directional coupler according to a second embodiment of the invention. As the coupler in fig. 3, it comprises a first dielectric layer 1 located above a second dielectric layer 2, which is located above a third dielectric layer 3, and also a first conductive layer 4 located on top of the first dielectric layer 1, a second conductive layer 5 located between the first dielectric layer 1 and the second dielectric layer 2, a third conductive layer 6 located between the second dielectric layer 2 and the third dielectric layer 3, and a fourth conductive layer 7 located below the third dielectric layer 3.

Coupled lines 8, 9, comprise a first line 8 formed in the first 4, and a second line 9 formed in the second conductive layer 5, whereby the coupled lines are, in a direction perpendicular to the plane of the layers, located at a first vertical distance from each other. In this embodiment, the first vertical distance is approximately equal to the thickness of the first dielectric layer 1. Further, the first and the second line 8, 9 are located at a first horizontal distance 14 from each other.

In the first conductive layer 4 a first ground plane 10, 10' is formed. In the third conductive layer 6 a second ground plane 11, 11' is formed, and in the second conductive layer 5 a third ground plane 12, 12' is formed. In the fourth conductive layer 7 a fourth ground plane 13 is formed, herein also referred to as a lower ground plane 13. The first 10, 10', second 11, 11', and third 12, 12' ground plane each include a first region 10, 11, 12, and a second region 10', 11', 12', which are, in a direction parallel to the ground planes and perpendicular to the longitudinal direction of the coupled lines 8, 9, located on opposite sides of the first line 8.

The first region of the second ground plane 11 is referred to as a tuning ground plane 11. It is, in a direction parallel to the ground planes and perpendicular to the longitudinal direction of the coupled lines 8, 9, located on the same side of the first line 8 as the second line 9. As can be seen in fig. 5, the second line 9 is, in a direction perpendicular to the ground planes, located between the first line 8 and the tuning ground plane 11. The first line 8 and the tuning ground plane 11 are formed in separate conductive layers, and therefore located at a second vertical distance from each other. In this embodiment, the second vertical distance is approximately equal to the sum of the thicknesses of the first 1 and the second 2 dielectric layer. Also, the first line 8 and tuning ground plane 11 are located at a second horizontal distance 15 from each other. In this embodiment the second vertical distance is larger than the first vertical distance. The lower ground plane 13 is, in a direction perpendicular to the tuning ground plane 11, located at a third vertical distance from the first line 8, whereby the third vertical distance is larger that any of the first or second vertical distances. The third vertical distance is approximately equal to the sum of the thicknesses of the first 1, a second 2 and a third 3 dielectric layer.

As in the first embodiment, the first 10 and the second 10' region of the first ground plane are placed with preferable equal distances 16, 17 from the first line 8, and the second region of the second ground plane 11' and the second region of the third ground plane 12', are preferably located at the same horizontal distance 16 from the

first line 8 as the second region of the first ground plane 10'. The first region of the second ground plane 12, which is located on the same side of the first line 8 as the tuning ground plane 11, is located at a distance 18 from the second line 9. The first region of the first 10, second 11 and third 12 ground plane and the lower ground plane 13 are connected by means of a plurality of via holes 19 placed along the coupled lines 8 and 9, and the second region of the first 10', second 11', and third 12' ground plane and the lower ground plane 13 are also connected by means of a plurality of via holes 19 placed along the coupled lines 8 and 9.

Fig. 6 shows results of calculations of the coupling coefficients, of the coupler described with reference to fig. 5, as a function of the horizontal distance 15 between the first line 8 and the tuning ground plane 11, and the horizontal distance 14 between the first 8 and the second 9 line as a parameter. The diagram includes the same parameters as the diagram in fig. 4, with the following exception: In fig. 6 the results are obtained by setting the horizontal distances 16, 17 (see fig. 5) between the first line 8 and the first 10 and the second 10' region of the first ground plane equal to the horizontal distance s, (15 in fig. 5), between the first line 8 and the tuning ground plane 11. However, as in the example described with reference to fig. 3 and 4, the horizontal distances 16, 17 between the first line 8 and the first 10 and the second 10' region of the first ground plane, and the horizontal distance 15 between the first line 8 and the tuning ground plane 11 could be dissimilar.

It can be seen in fig. 6 that with the coupler according to the second embodiment essentially the same wide range of weak couplings is achievable while being compensated, as with the coupler according to the first embodiment. In the second embodiment, the tuning ground plane 11 plays an even more important role in achieving compensation conditions. Accompanying widths of the first line 8 and the second line 9, assuring the matching to 50 Ohms condition, vary from 104 to 130 mils and from 21 to 40 mils, respectively.

In the first and second embodiments, presented with reference to fig. 3 and 5, respectively, the configurations utilized the conductor-backed coplanar line 8 on the first conductive layer 4 and quasi strip line 9 on the third 6 or on the second 5 conductive layer.

Fig. 7 shows a further embodiment, in the form of a microstrip – quasi strip line configuration, whereby positions of a first line 8, a second line 9 and a tuning ground plane 11 correspond to the positions of the respective corresponding elements in the configuration shown in fig. 3. A lower ground plane 13 is present below the second line 9. The embodiment shown in fig. 7 differs from the embodiment shown in fig. 3 in that, at least in a vicinity of the coupled lines 8, 9, there are no ground planes at conductive layers in which the first line 8 and the second line 9 are formed. Also, a part corresponding to the second region 11' of the second ground plane in the embodiment shown in fig. 3 is not present in the embodiment shown in fig. 7. In the embodiment in fig. 7, the first line 8 and the lower ground plane 13 form a microstripline configuration, in which the first line 8 is a microstripline 8, and the second line 9, the tuning ground plane 11 and the lower ground plane 13 form a stripline configuration, in which the second line 9 is a quasi strip line 9.

Surprisingly, it has been found that weak couplings at compensation conditions can be obtained with a big difference in propagation velocities of two orthogonal modes propagated in the coupled lines. This is illustrated in fig. 8 in which effective dielectric constants calculated for two orthogonal modes propagated in the coupled lines in configuration shown in fig. 7, and a cross-section corresponding to the one in fig. 7 to explain variables in the diagram, are presented. Dielectric permittivity of the dielectric layers is chosen to be the same for each layer, and equal to 3.6. In fig. 8, eps eff c corresponds to the wave propagated in the stripline 9. Notice, that if the stripline 9 is covered with the tuning ground plane 11, which corresponds to small values of s, effective dielectric constant for this mode is equal to the dielectric permittivity of the dielectric layers, as it should be for the stripline 9. eps eff pi corre-

sponds to the wave propagated in the microstripline 8 and differs very much from eps eff c.

Preferably, an electrical length of the directional coupler, i.e. the distance on which the first and the second lines are coupled, is a quarter or less of length of the propagated wave – how to calculate this length for two modes propagated with different velocities see the above mentioned article: K. Sachse, A. Sawicki, Quasi-ideal multilayer two- and three-strip directional couplers for monolithic and hybrid MICs, IEEE Trans. MTT, vol. 47, No. 9, Sept. 1999, pp. 1873 – 1882.

Further modifications of the configurations described above are possible within the scope of the present invention. On the side of the first line 8 opposite to the side where the second line 9 and the tuning ground plane 11 are positioned, any arrangement of the ground planes 10', 11' and 12' is possible. Thereby, only some of the latter can be present, or all of them can be omitted. The ground planes positioned at the vicinity of the first 8 or the second line 9 can be useful for tuning these lines to the terminating impedance (50 Ohms) at convenient geometrical dimensions.

Fig. 9 shows an alternative configuration in which positions of a first line 8, a second line 9 and a tuning ground plane 11 corresponds to the positions of the respective corresponding elements in the configuration shown in fig. 7. Additionally, a second ground plane region 11' formed in the same conductive layer as the tuning ground plane is presented, in a horizontal direction, on the opposite side of the first line 8. Also, in a horizontal direction, on the same side of the first line 8 as the tuning ground plane 11, a first ground plane 10 is formed on the same conductive layer as the first line 8, and located at a distance 17 from the latter.

In the embodiments described above, the first line 8, whether in the form of a coplanar or a microstrip line, works in the coupler as a power carrying line. Fig. 10 shows an alternative embodiment, in which positions of a second line 9 and a tuning

ground plane 11 corresponds to the positions of the respective corresponding elements in the configuration shown in fig. 3. A first line is stacked, whereby an auxiliary line 20 on a second conductive layer 5 is located below a line 8 on a first conductive layer 4 and connected to the line 8 utilizing at least one, preferably a plurality of via holes 21 placed along the lines 8 and 20. This will extend the power handling capability of the line 8.

The configurations in fig. 3, 7, and 9 where the microstrip line 8 and the stripline 9 are placed on top of each other, with the ground plane 11 separating these two propagation media, provide for manufacturing couplers of high scale of integration, with a relatively small size, which is a big advantage in many applications.

CLAIMS

1. A directional coupler comprising coupled lines (8, 9) including a first (8) and a second (9) line, **characterized in**

- that it comprises a tuning ground plane (11),
- that, in a direction perpendicular to the tuning ground plane (11), the first (8) and the second (9) line are located at a first vertical distance from each other,
- that, in a direction perpendicular to the tuning ground plane (11), the first line (8) and the tuning ground plane (11) are located at a second vertical distance from each other,
- that, in a direction parallel to the tuning ground plane (11) and perpendicular to a longitudinal direction of the coupled lines (8, 9), the first (8) and the second (9) line are located at a first horizontal distance (14) from each other,
- that, in a direction parallel to the tuning ground plane (11) and perpendicular to the longitudinal direction of the coupled lines (8, 9), the first line (8) and the tuning ground plane (11) are located at a second horizontal distance (15) from each other, and
- that it comprises a lower ground plane (13), which, in a direction perpendicular to the tuning ground plane (11), is located at a third vertical distance from the first line (8), whereby the third vertical distance is larger that any of the first or second vertical distances.

2. A directional coupler according to claim 1, first vertical distance is larger than the second vertical distance.

3. A directional coupler according to claim 1, first vertical distance is shorter than the second vertical distance.

4. A directional coupler according to any of the preceding claims, comprising at least four conductive layers, whereby at least three dielectric layers are interposed between the conductive layers.

5. A directional coupler according to claim 4, whereby at least one ground plane (10, 10') is formed in a vicinity of the first line (8) on the same conductive layer (4).

6. A directional coupler according to claim 4 or 5, whereby at least one ground plane (12, 12') is formed in a vicinity of the second line (9) on the same conductive layer.

7. A directional coupler according to any of the preceding claims, whereby an auxiliary line (20), in a direction perpendicular to the tuning ground plane (11), is located at a fourth vertical distance from the first line (8) and connected thereto with at least one via hole (21).

8. A directional coupler according to any of the preceding claims, whereby an electrical length of the directional coupler is a quarter or less of length of the propagated wave.

ABSTRACT

A directional coupler is presented comprising a first line (8), a second line (9), and a tuning ground plane (11). The first (8) and the second (9) line are located at a first vertical distance from each other, and the first line (8) and the tuning ground plane (11) are located at a second vertical distance from each other. The first (8) and the second (9) line are located at a first horizontal distance (14) from each other, and the first line (8) and the tuning ground plane (11) are located at a second horizontal distance (15) from each other. It comprises a lower ground plane (13) which, in a direction perpendicular to the tuning ground plane (11), is located at a third vertical distance from the first line (8), whereby the third vertical distance is larger that any of the first or second vertical distances.

Fig. 3

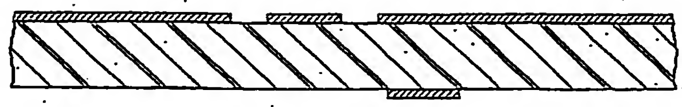


Fig. 1

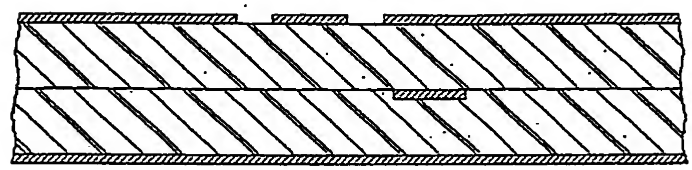


Fig. 2

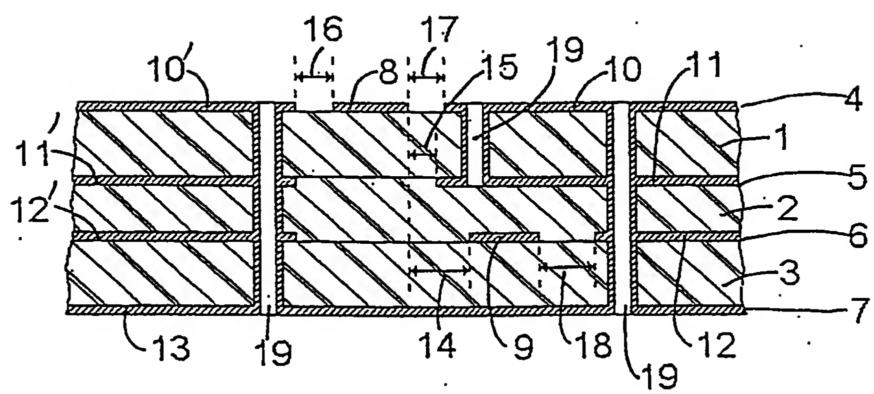
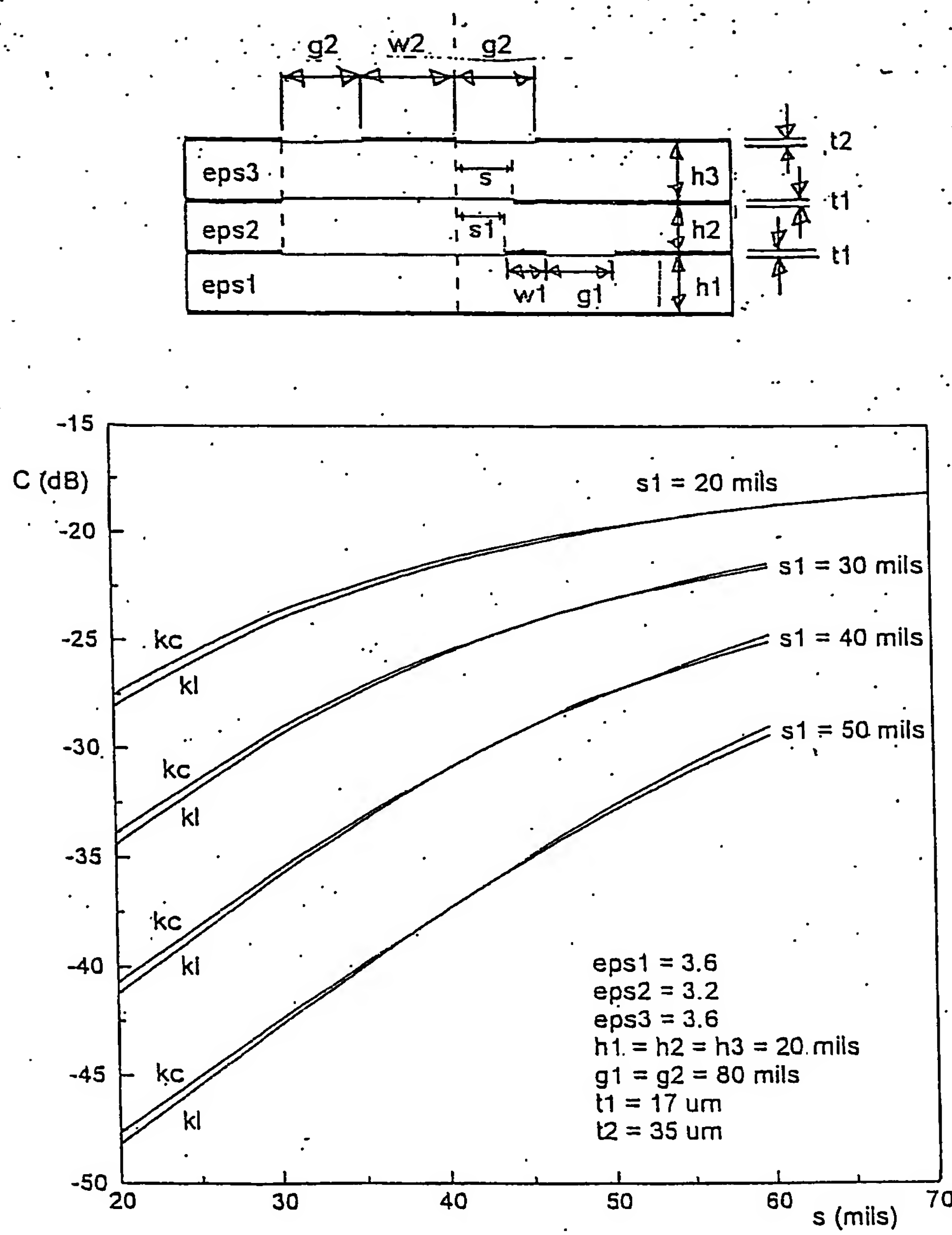


Fig. 3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C (dB)
-20
-25
-30
-35
-40
-45
-50
20
30
40
50
60
70
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s1 = 20 mils
s1 = 30 mils
s1 = 40 mils
s1 = 50 mils
kc
kl
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eps1 = 3.6
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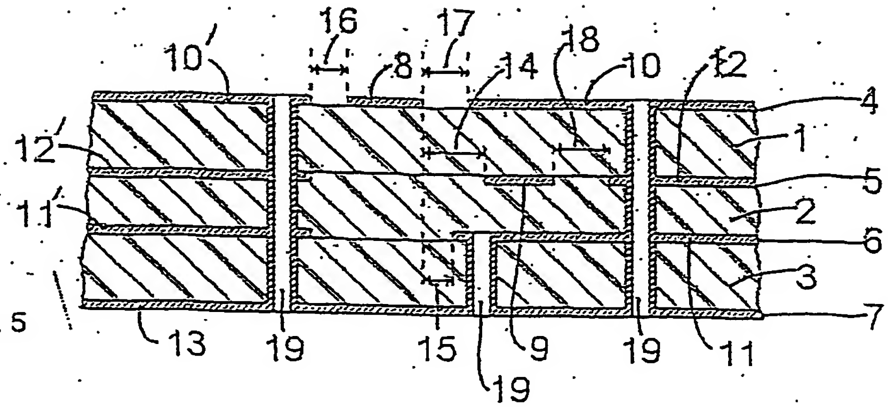
t2 = 35 um

Fig. 4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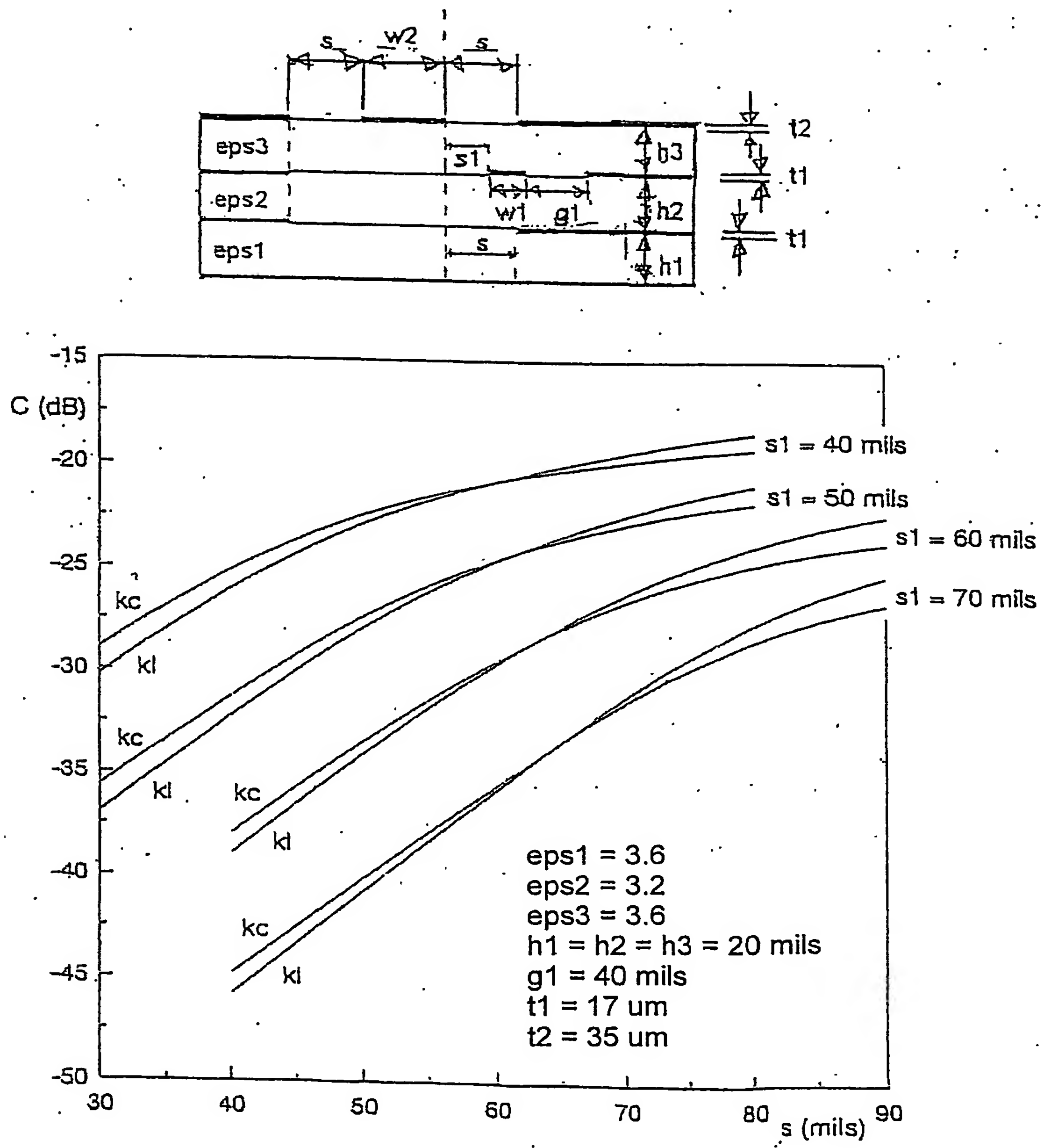
19

Fig. 5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s1 = 60 mils
s1 = 70 mils
kc
kl
eps1 = 3.6
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Fig. 6

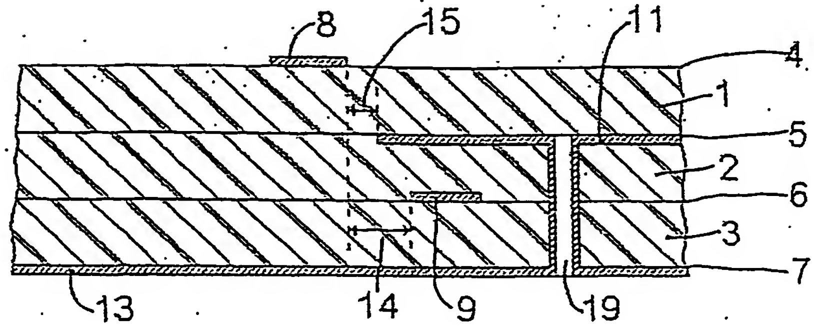

Fig. 7

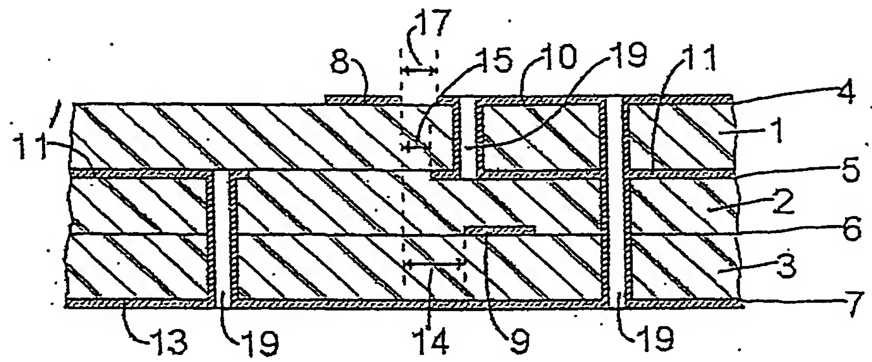

Fig. 9

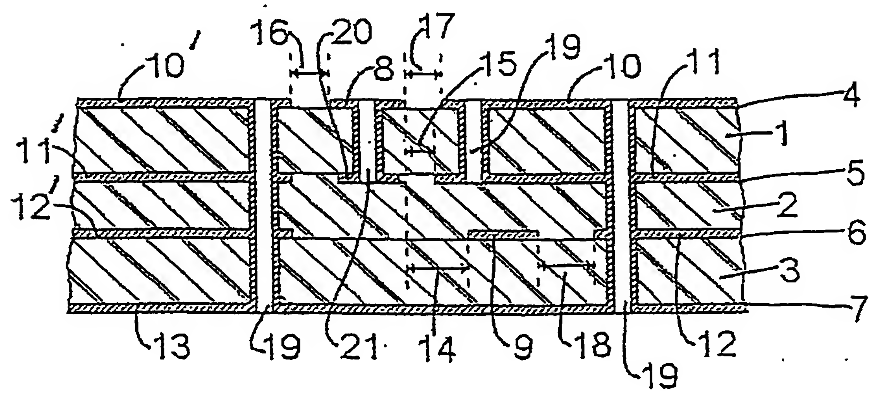

Fig. 10

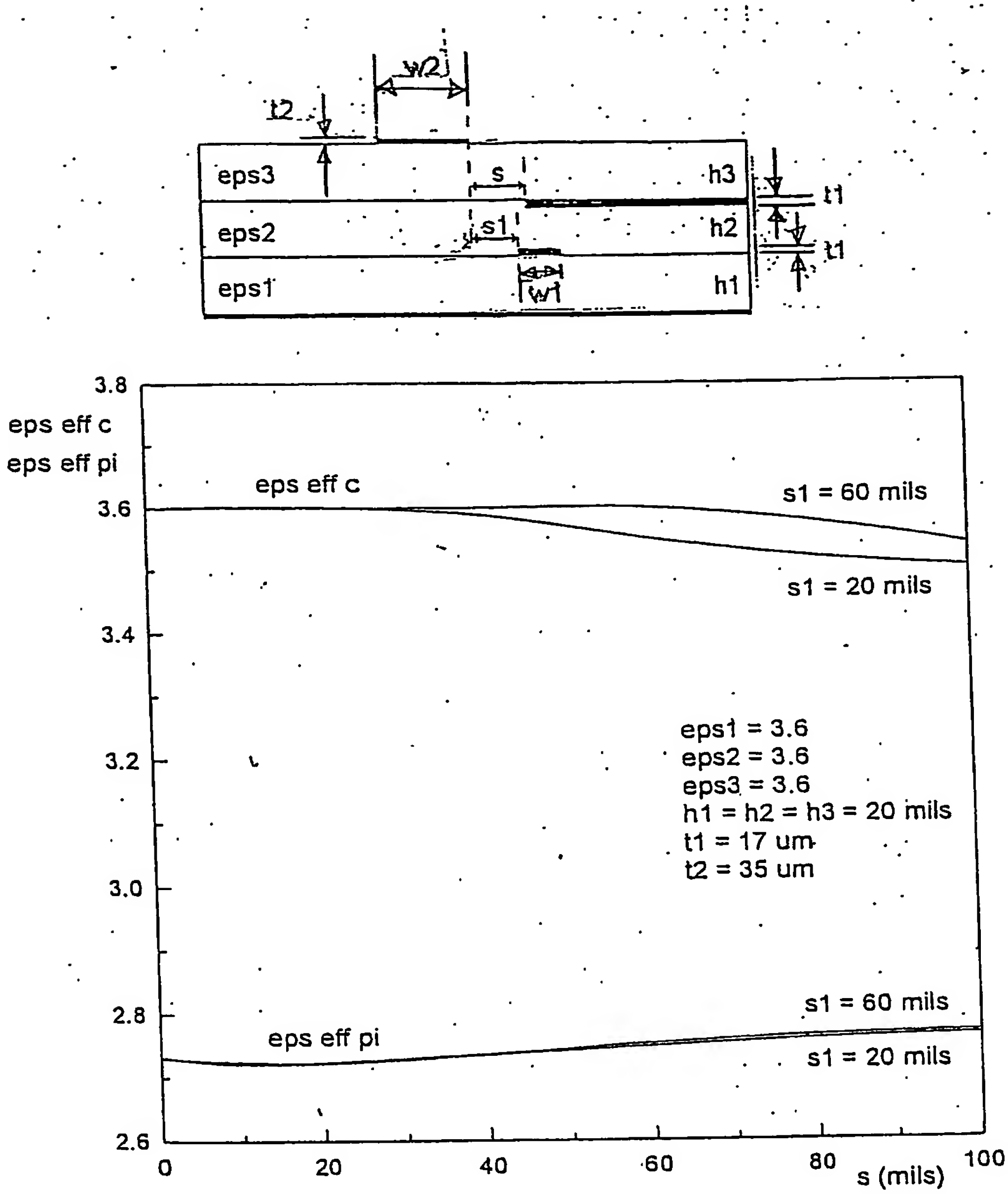
t2
w2
eps3
s
h3
t1
eps2
s1
h2
t1
eps1
w1
h1
eps eff c
eps eff pi
3.8
3.6
3.4
3.2
3.0
2.8
2.6
eps eff c
s1 = 60 mils
s1 = 20 mils
eps1 = 3.6
eps2 = 3.6
eps3 = 3.6
h1 = h2 = h3 = 20 mils
t1 = 17 um
t2 = 35 um
eps eff pi
s1 = 60 mils
s1 = 20 mils
0
20
40
60
80
100
s (mils)

Fig. 8

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